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Progress on Assessment of NSTX Divertor Particle and Heat Fluxes

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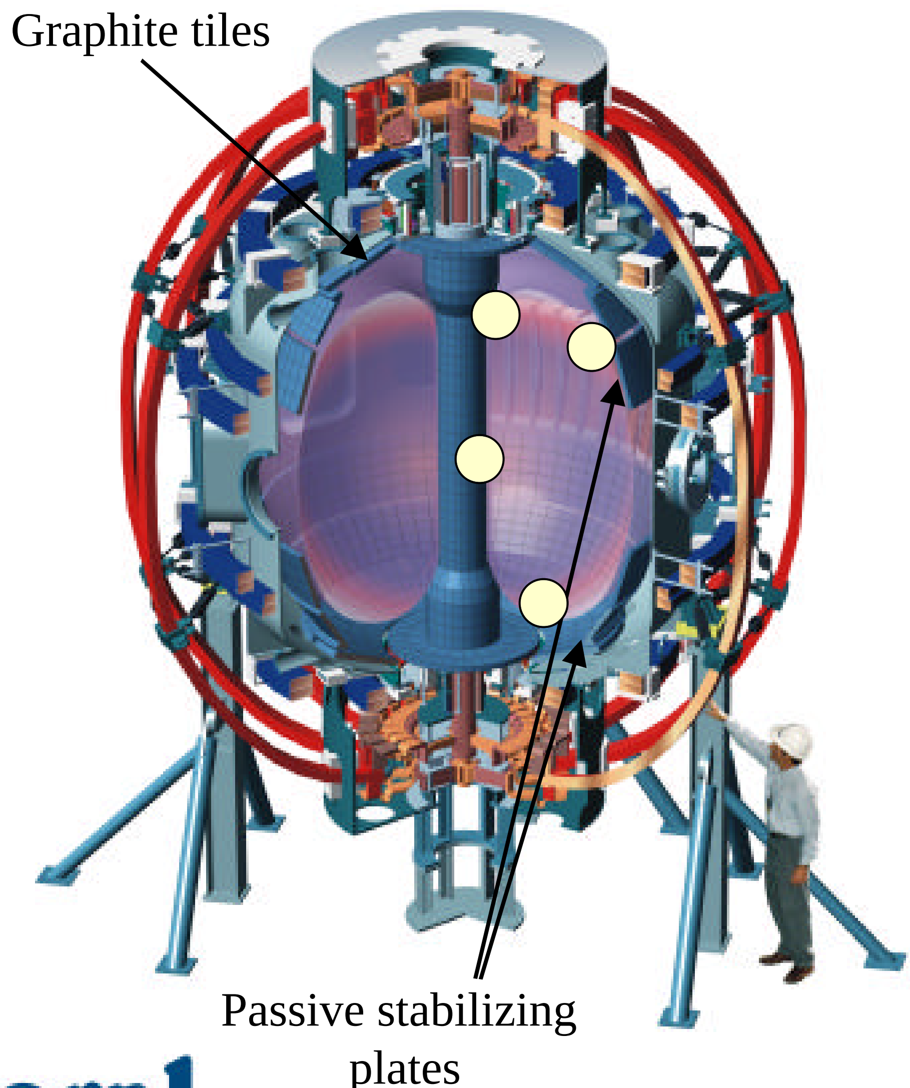
NSTX Fueling Observations

- NSTX H-modes suffer uncontrolled density rise
  - Due to limited fueling control from center stack injector?
- NSTX L-modes also exhibit density rise
  - No center stack injector used

-> NSTX generally has high recycling

- Recycling control needed, but where are particles and power?

NSTX Explores Low Aspect Ratio (A=R/a) physics regime

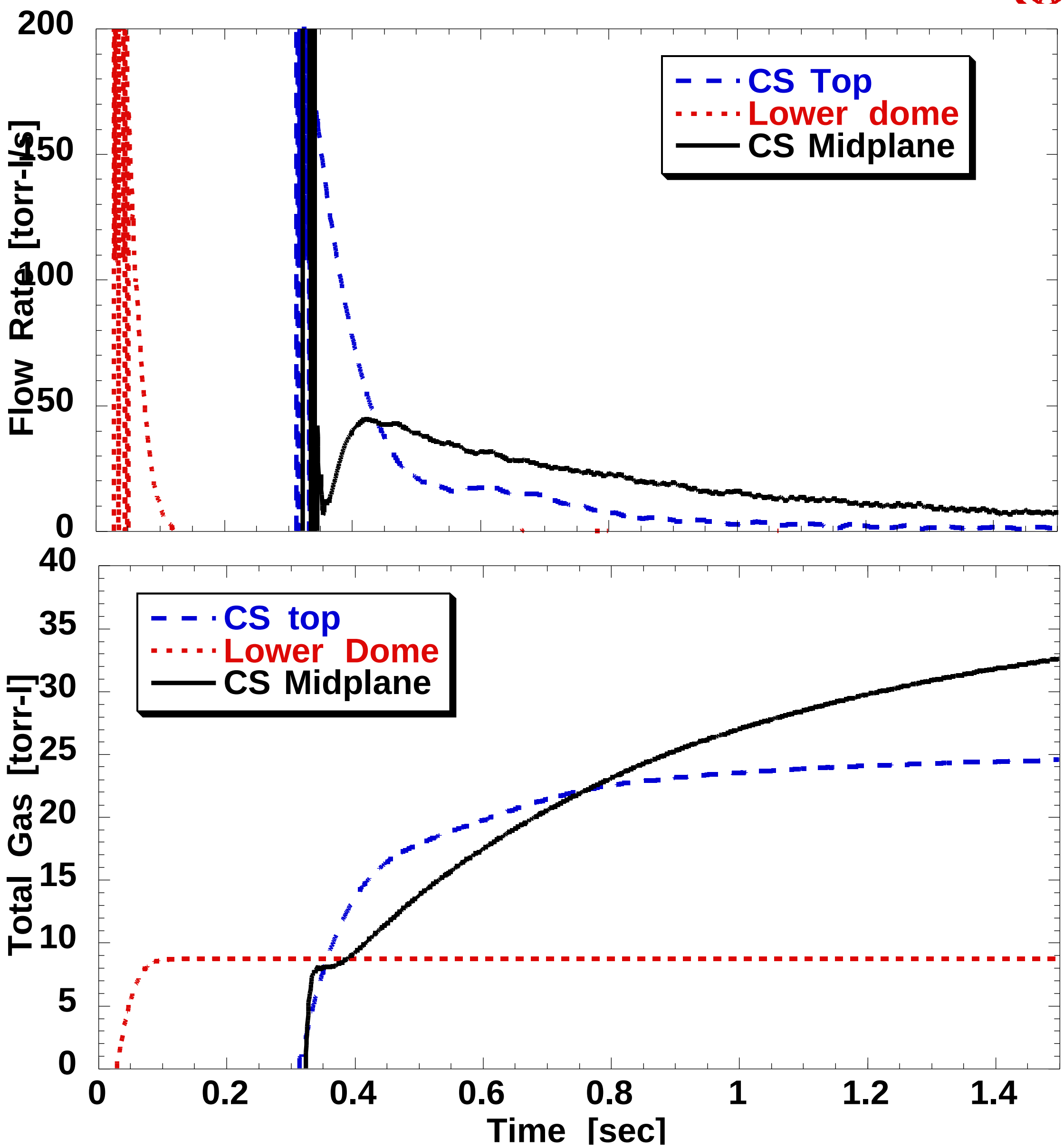


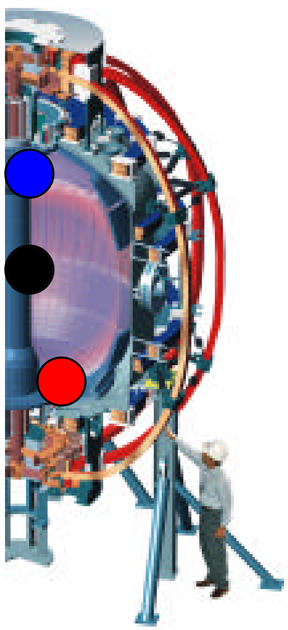
Parameters	**Design**	Achieved
Major Radius	0.85m	A ≥ 1.27
Minor Radius	0.67m	
Plasma Current	1MA	1.5MA
Toroidal Field	0.6T	0.6T
Heating and Current Drive		
NBI (100keV)	5MW	7 MW
RF (30MHz)	6MW	6 MW

Wall Conditioning:

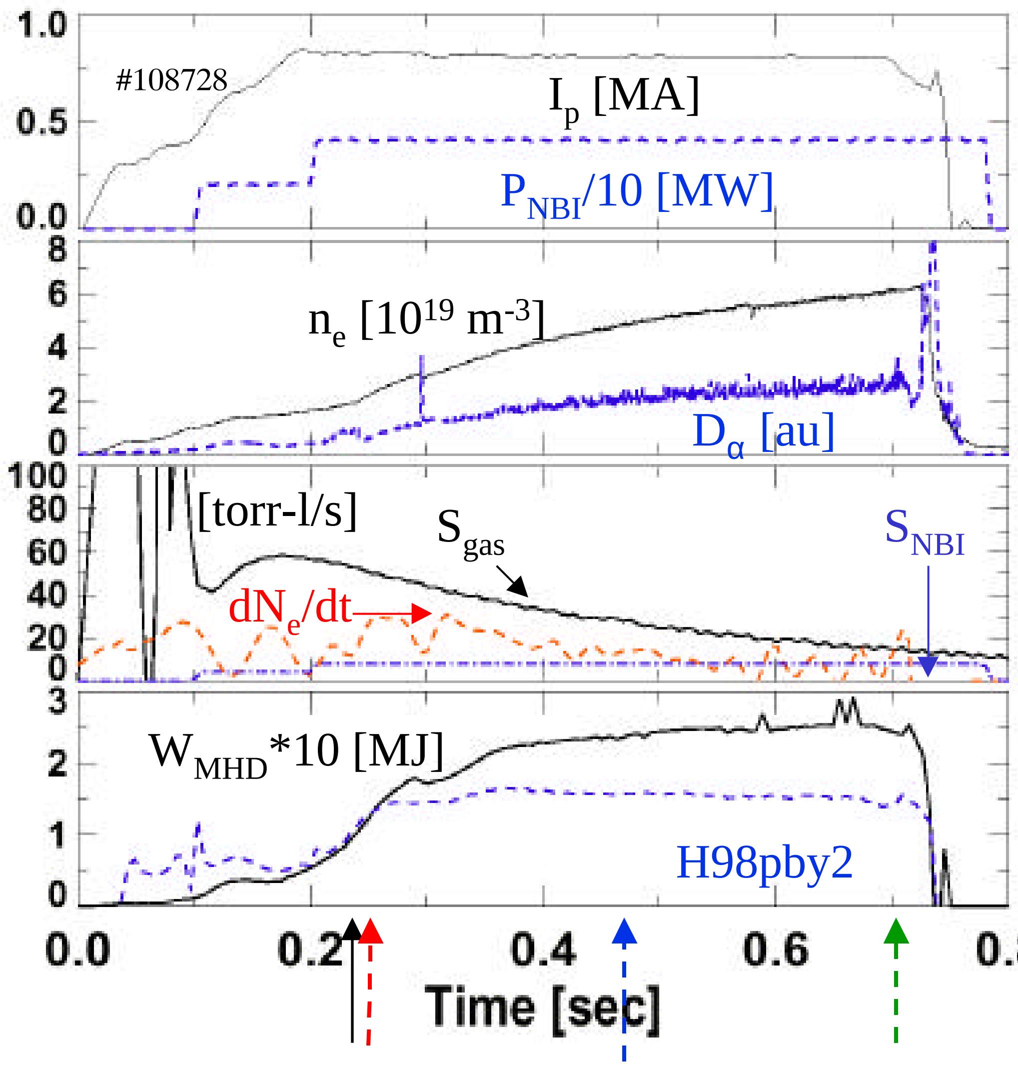
350 deg. bakeout of graphite tiles
Regular boronization (~3 weeks)
Helium Glow between discharges
Center stack gas injection

Load-and-Dump Gas Injectors Have Different Flow Characteristics and Delay Time

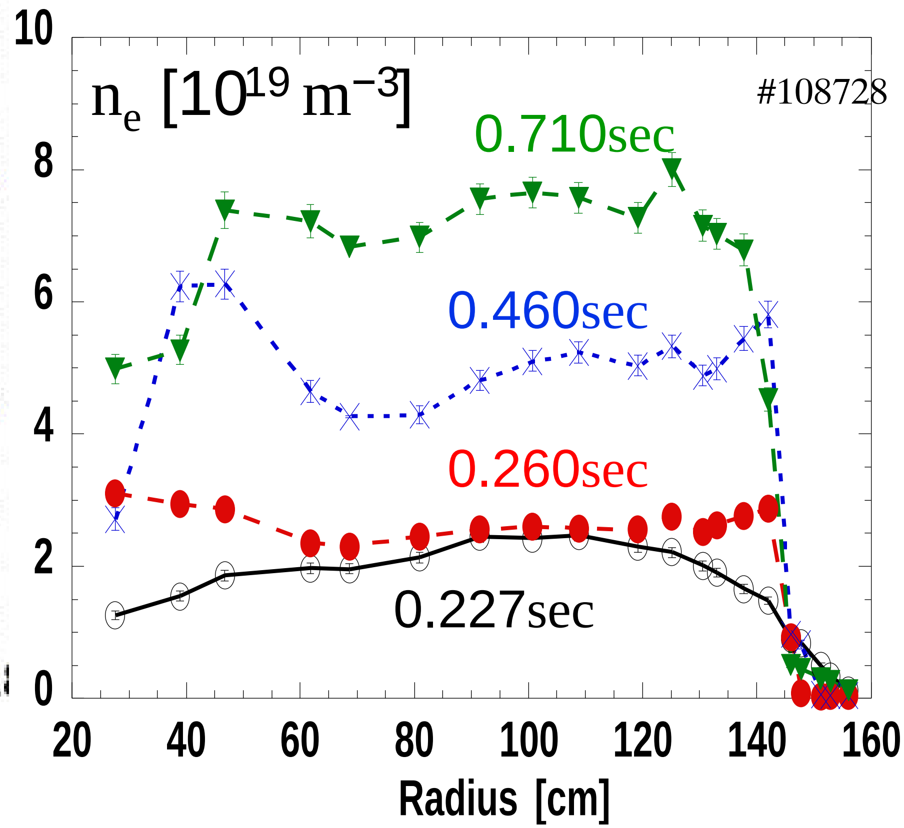




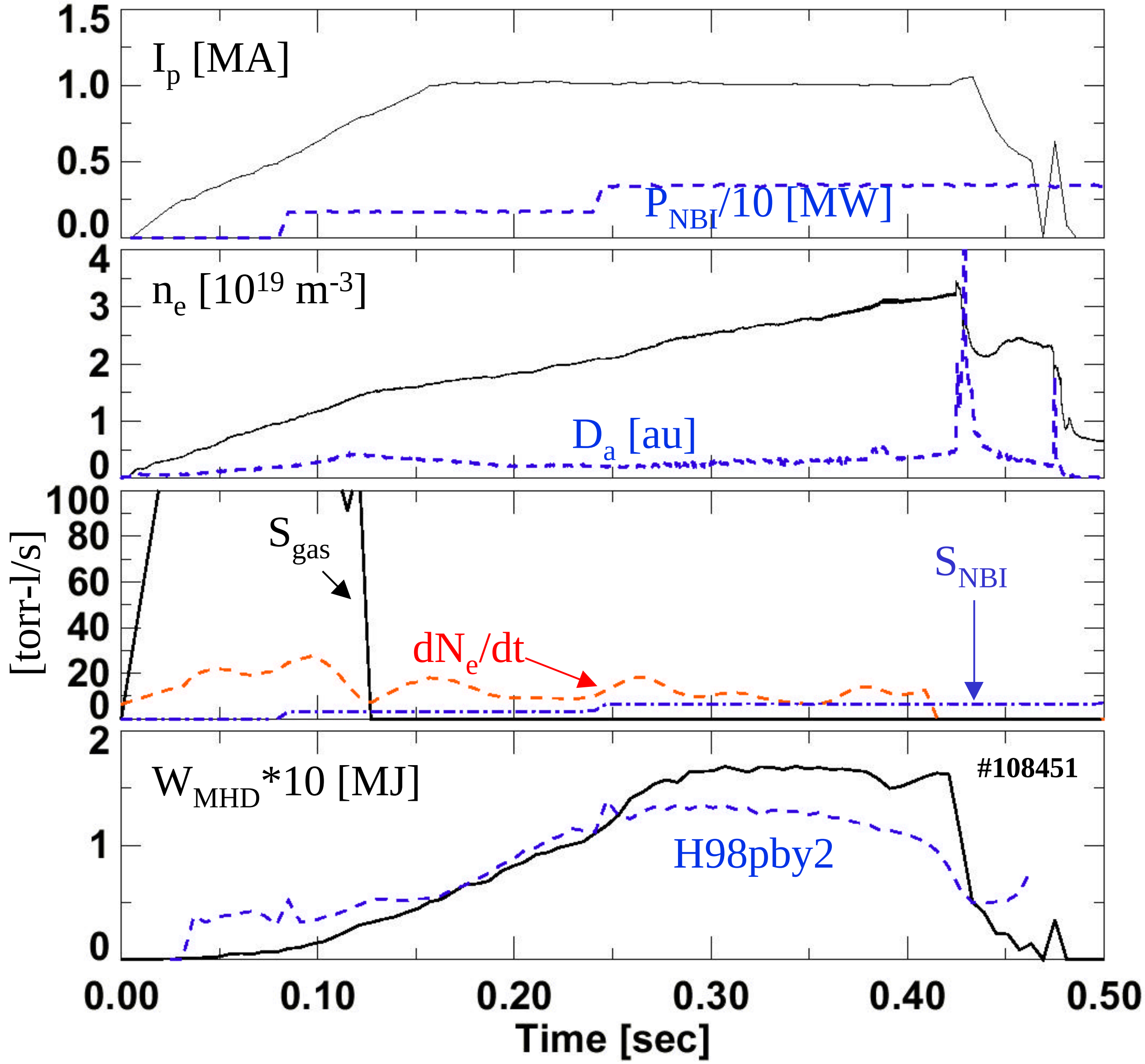
Uncontrolled (non-disruptive) density rise in long pulse H-modes



- Density control needed for improved current drive efficiency, transport studies, and power and particle handling research



Density also rises faster than NBI fuel rate in long pulse L-modes



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Classic Particle Balance Model used to Estimate Particle Containment Time

NSTX

- Assuming constant NBI and gas source term, time dependence of plasma content has analytic solution

$$\frac{dN}{dt} = \eta_{NBI} S_{NBI} + \eta_{gas} S_{gas} - \frac{N}{\tau_p^*}$$

where $\tau_p^* = \dfrac{\tau_p}{1 - R_{eff}}$

$$N(t) = N_o \exp\left(-\frac{t}{\tau_p^*}\right) + \tau_p^* \left(\eta_{NBI} S_{NBI} + \eta_{gas} S_{gas}\right)\left(1 - \exp\left(-\frac{t}{\tau_p^*}\right)\right)$$

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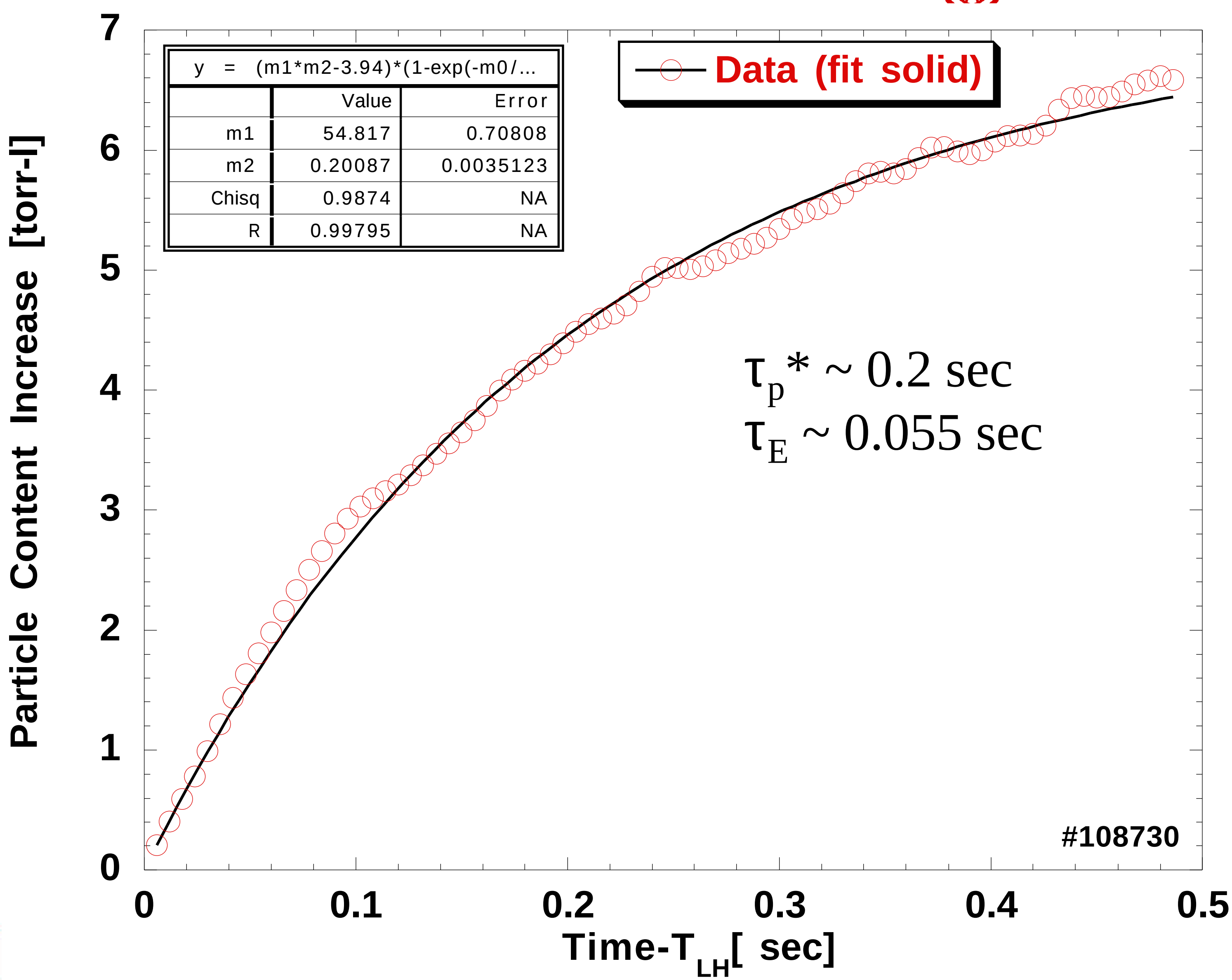
Particle Containment Times ~ 0.2-0.3 sec. in NSTX with constant gas fueling rate model



Classic Density Rise Model Can Be Modified with Realistic Time Dependencies

NSTX

- Assuming time dependent gas source term; time dependence of plasma content has analytic solution

$$\frac{dN}{dt} = \eta_{NBI} S_{NBI} + \eta_{gas} S_{gas}(t) - \frac{N}{\tau_p^*}$$

$$\text{where } S_{gas}(t) = S_{gas,0} \exp\left(-\frac{t}{\tau_{gas}}\right); \tau_{gas} \sim 0.55 \sec$$

$$N(t) - N_o = \left(\eta_{NBI} S_{NBI} \tau_p^* - N_o\right)\left(1 - \exp\left(-\frac{t}{\tau_p^*}\right)\right) + \frac{\eta_{gas} S_{gas,0} \tau_{gas} \tau_p^*}{\tau_{gas} - \tau_p^*}\left[\exp\left(-\frac{t}{\tau_{gas}}\right) - \exp\left(-\frac{t}{\tau_p^*}\right)\right]$$

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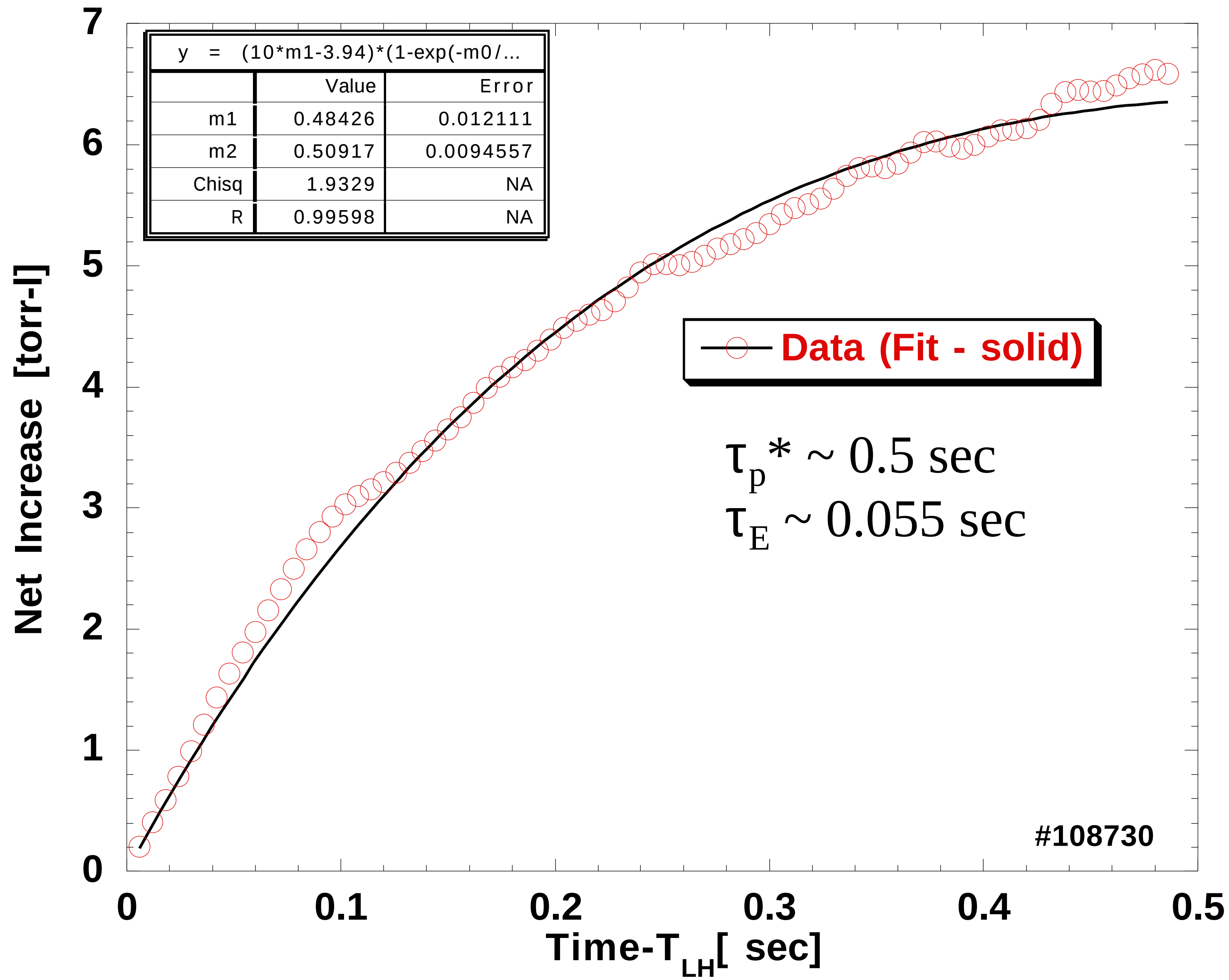
Particle Containment Times ~ 0.5 sec. in NSTX with more realistic gas fueling rate model



In all models, $\tau_p^* \sim 0.5$ sec >> τ_E, i.e. $R_{eff} > 0.5$
>> NSTX is almost always high recycling with NBI

- **Solutions to More Realistic Dependencies of Fueling Terms in Progress, i.e.**

$$\tau_p^*(t) = \tau_{p,0}^*(1+\alpha t) \text{ (some L}-\text{modes with increasing confinement or recycling)}$$

$$S_{gas}(t) = S_{gas,0}(1+\alpha t) \text{ (source increasing/decreasing with time)}$$

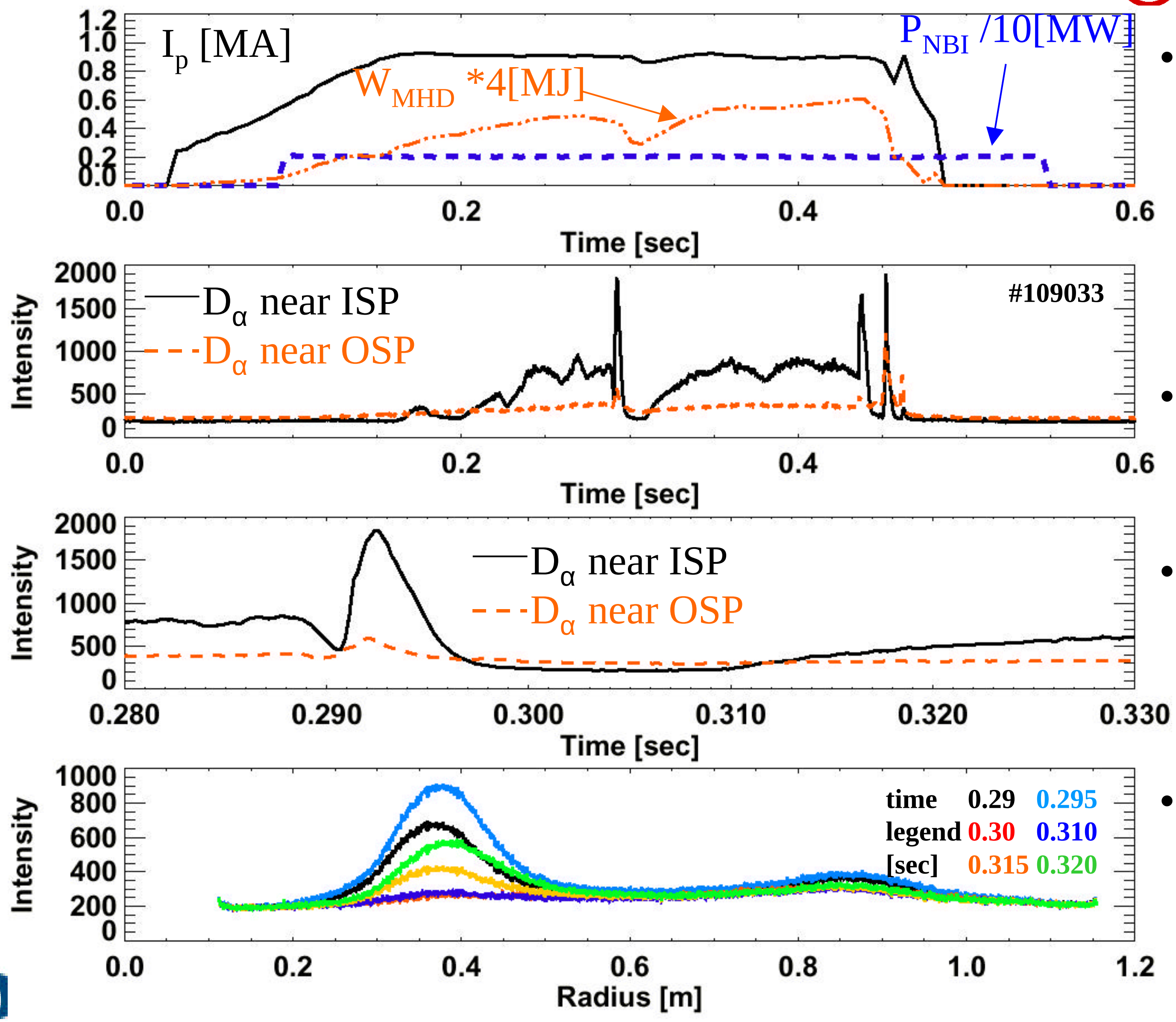
$$\eta_{gas}(t) = \eta_{gas,0} \exp\left(-t/\tau_p^*\right) \text{ (fuel efficiency decreasing with time)}$$

$$\eta_{gas}(t) = \eta_{gas,0} / N(t) \text{ (fuel efficiency decreasing with density)}$$

Where are particles and power in NSTX divertor?

- D_α peaks near inner and outer strike points, inner ~ 3x outer
  - Ratio reverses during power excursion -> inner probably detached
  - Most particles on outer side -> consistent with module location
- Heat flux always peaks near outer strike point
  - inner strike point peak heat flux and power < 1/3 outer values
  - > consistent with module location

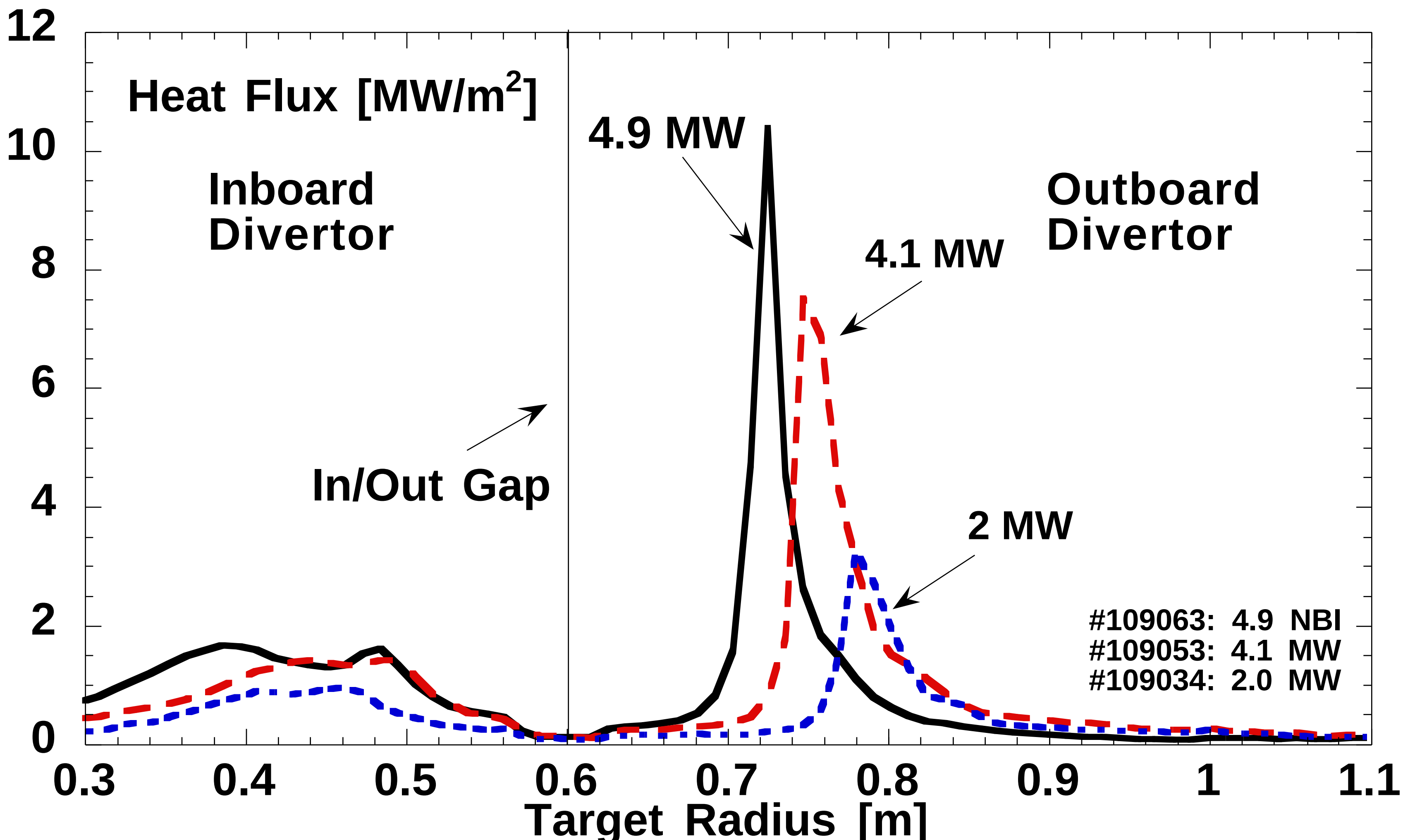
D_α profile normally peaks near Inner Strike Point, but reverses during heat pulse



- Reversal of in/out D_α profile during heat pulse is consistent with inner side being detached
- Similar situation in pre-cryopump days at DIII-D
- Reduced recycling will probably re-attach ISP, so D_α will go down
- Likely more particles near OSP; need LP data to confirm

Peak heat flux always peaks near outer strike point in lower-single null configuration

- Good power accountability: P_{div}^{in+out} ~ 70% of P_{SOL}



Progress on Assessment of NSTX Divertor Particle and Heat Fluxes

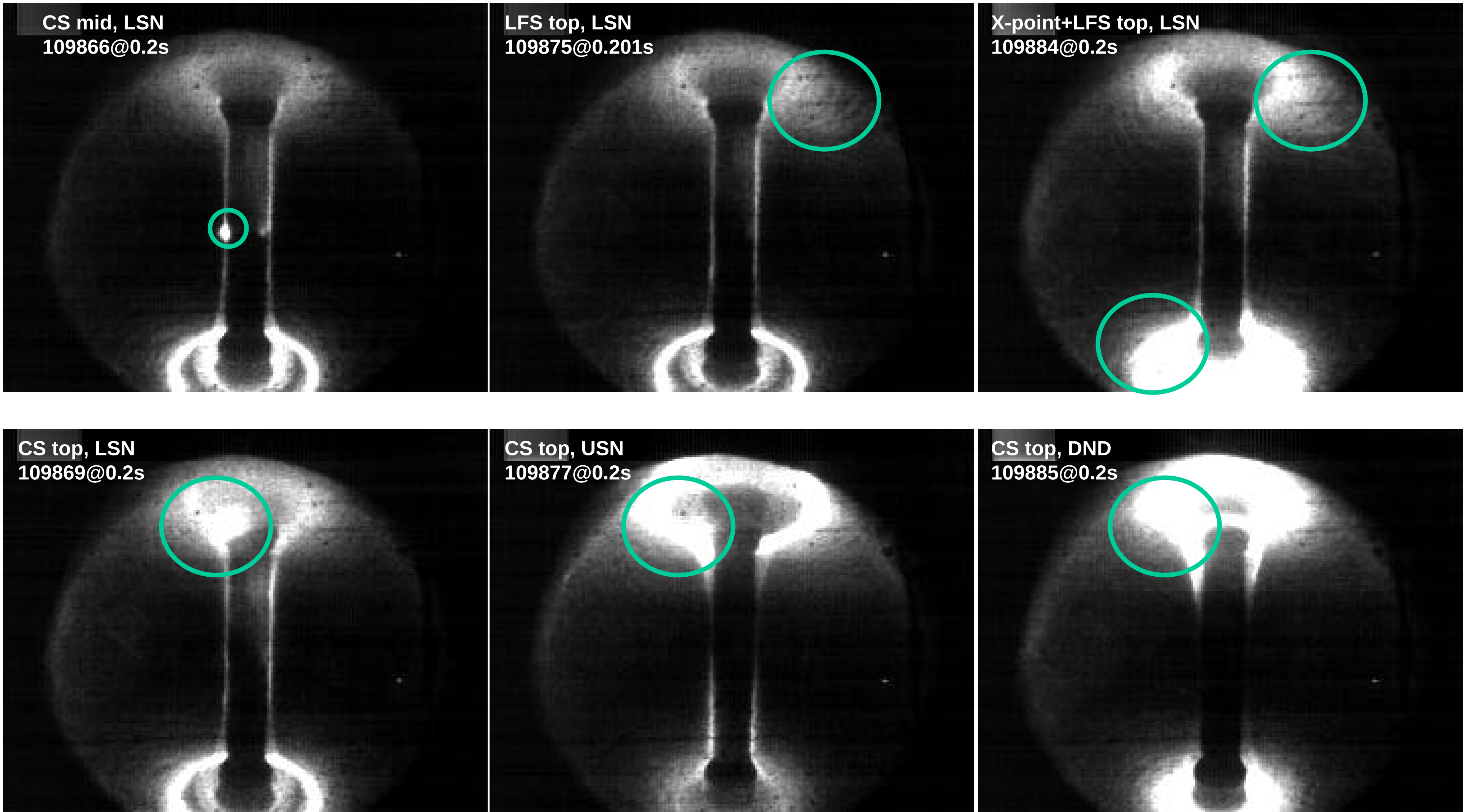
- NSTX is always (99%) in moderate-high recycling state and suffers from uncontrolled density rise
  - L-mode density increases with NBI fueling; no need for gas puffing
  - H-mode density increase > NBI fuel rate; τ_p* ~ 0.2-0.5 sec

-> Density control needed, but where are particles and power?

- D_α peaks near inner and outer strike points, inner ~ 3x outer
  - Ratio reverses during power excursion -> inner probably detached
  - Most particles on outer side -> consistent with module location
- Heat flux always peaks near outer strike point
  - inner strike point peak heat flux and power < 1/3 outer values
  - > consistent with module location
- UEDGE modeling in progress; DEGAS-2/TRANSP to follow to estimate effect of lower recycling

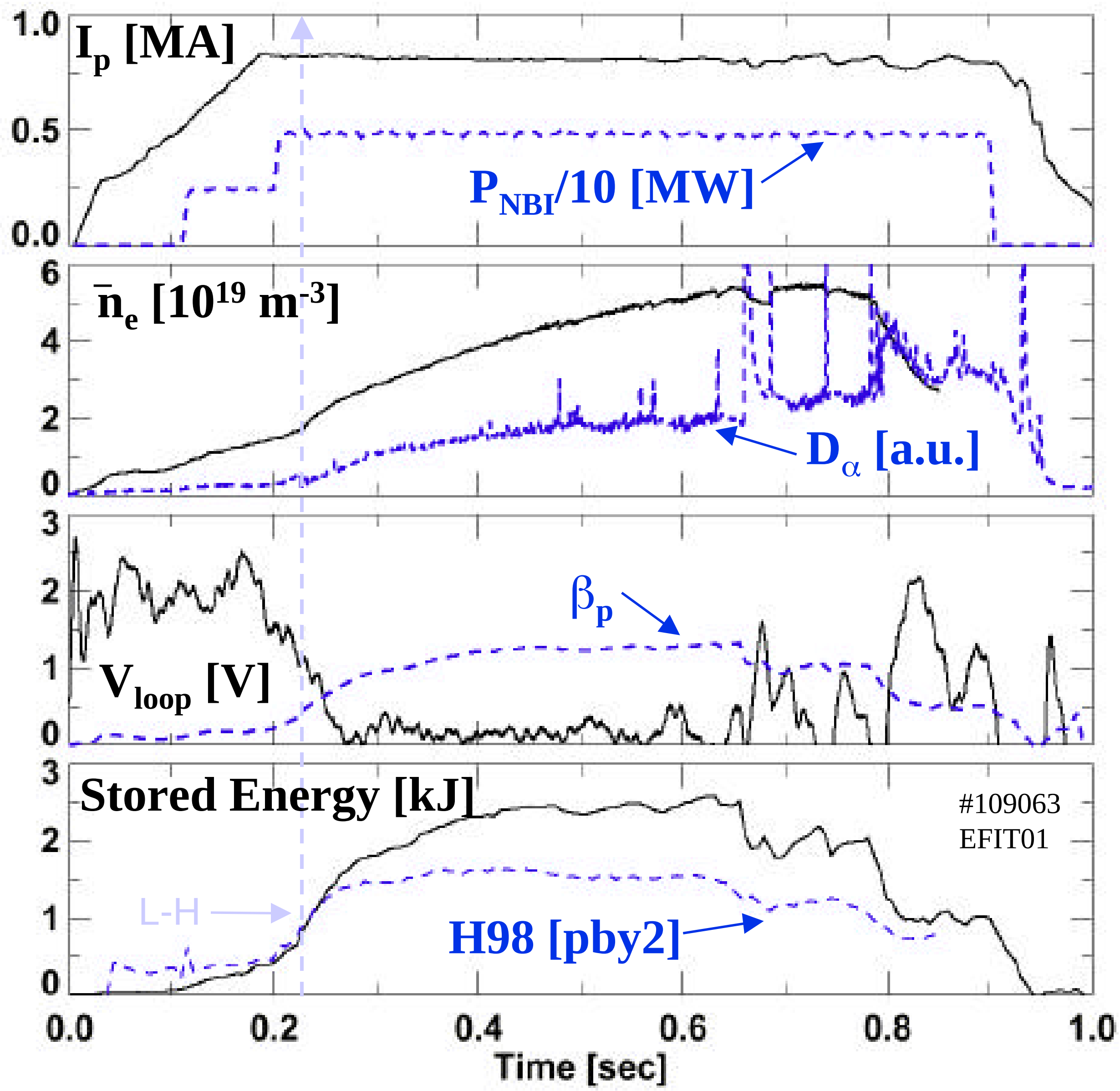
Backup: H-mode slides

Different Gas Puffers Light up Different Plasma Regions (unfiltered)



H-mode Plasmas Achieved Long Pulse, Owing to Low Volt-Second Consumption Rate

NSTX



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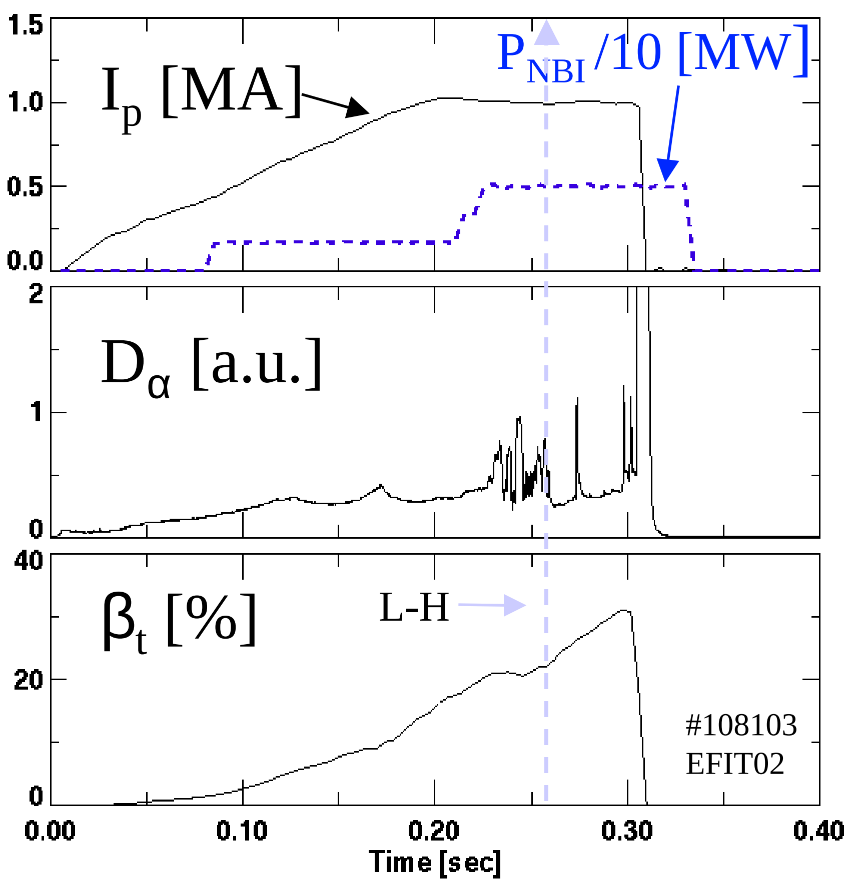
H-mode Plasmas Achieved High β_t, Owing to Reduced Pressure Peaking Factor

NSTX

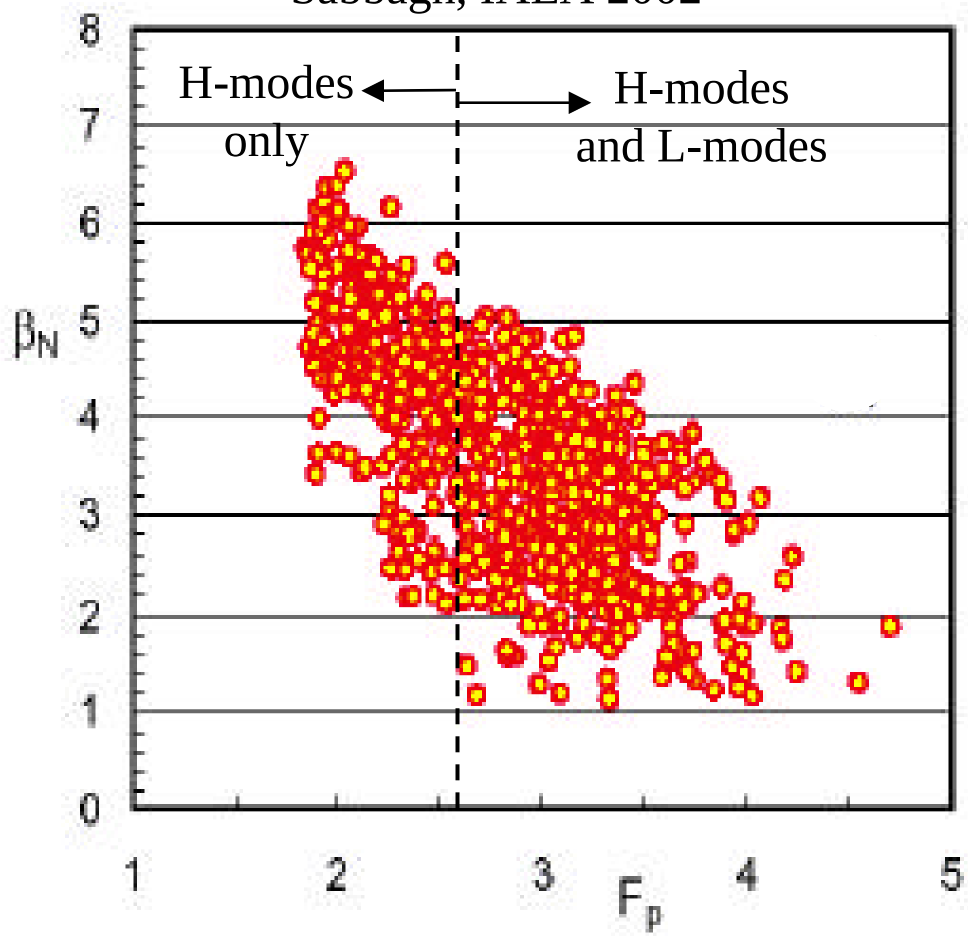
Max β_T = 31.5%
β_N^{max} ~ 6.2

$\beta_T = 2\mu_o\langle p\rangle/B_0^2$



Min f_p(H) ~ 1.9, Min f_p(L) ~ 2.6
$f_p \equiv p_e/\langle p_e\rangle$

Sabbagh, IAEA 2002



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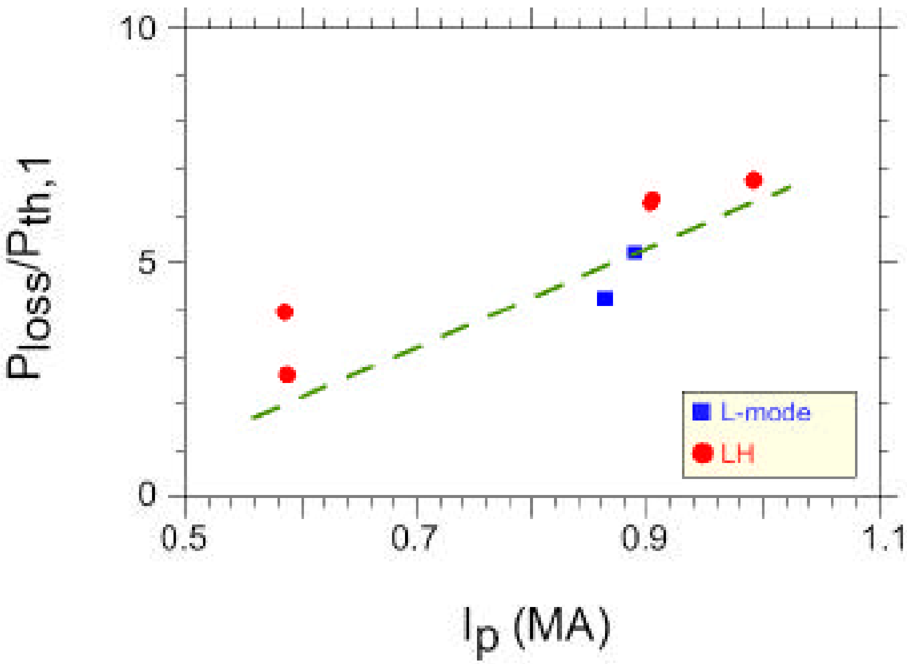
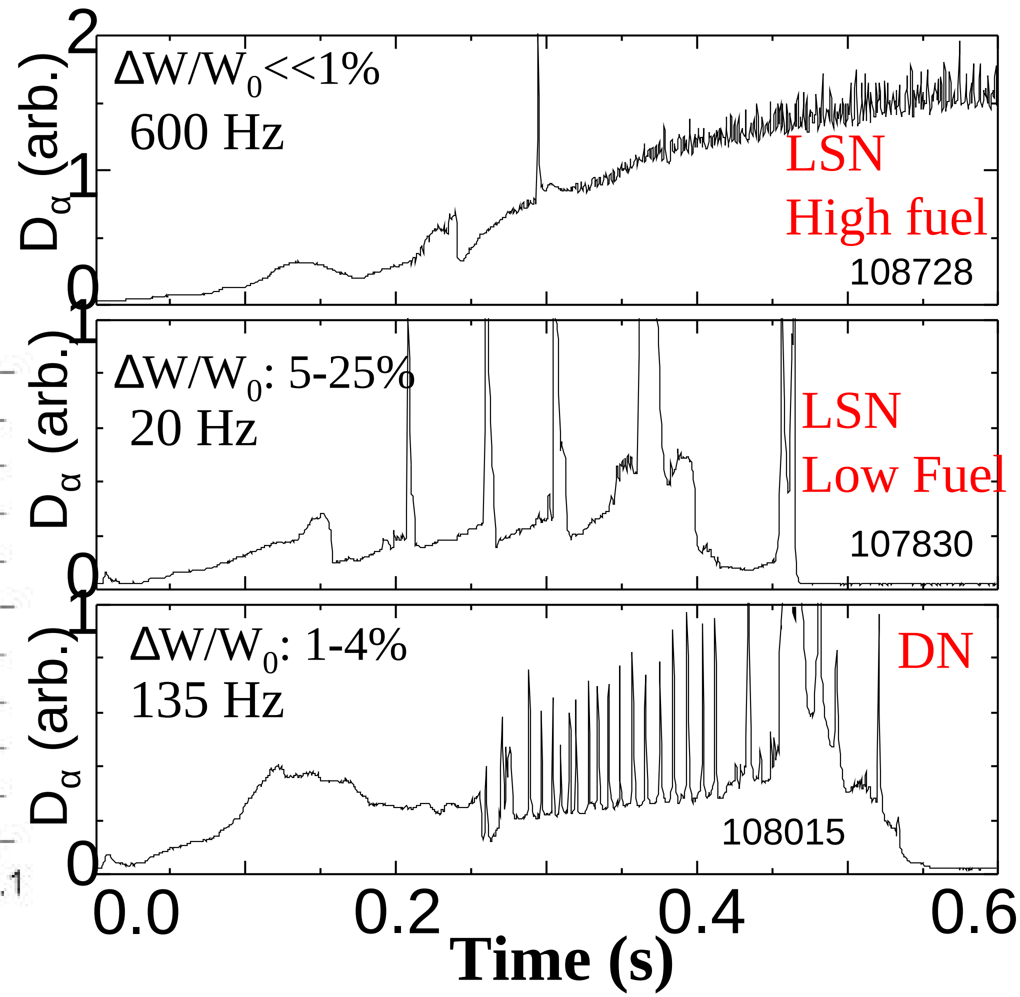
L-H power threshold and ELM studies reveal differences with conventional aspect ratio tokamaks

- L-H transition: $P_{L\text{-}H}^{NSTX} > P_{th,1}$
- I_p dependence
  - related to E_r through fast ion loss?

$$P_{th,1} \sim n_e^{0.61} B_T^{0.78} a^{0.89} R^{0.94}$$





Bush, ORNL